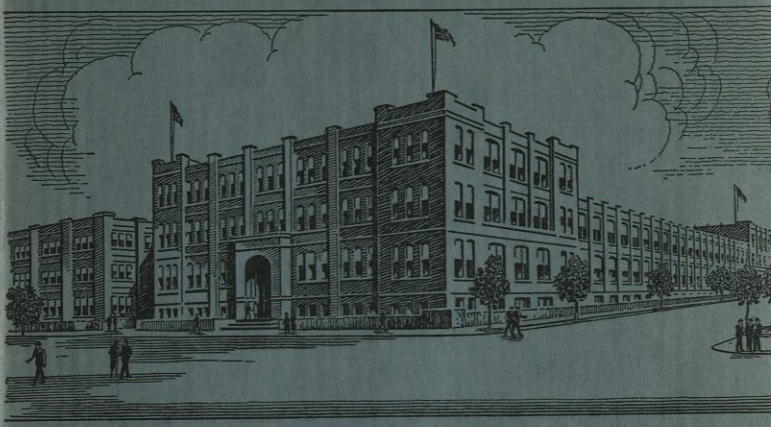

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PENNSYLVANIA

Walschaert Valve Gear

Prepared Especially for Home Study

By

J. W. HARDING

Former Director, Steam Railroad School
International Correspondence Schools

4003 A-3 Part 1 Edition 2

An Unbeatable Combination

In 1837 there was a young fellow named John Deere . . . a blacksmith. He saw a human need and thought he could serve it. Many farm lands had sticky soil that stuck to the plows and made plowing difficult. Deere concentrated all his efforts on making a self-polishing plow.

Today Deere and Company is a $250,000,000 corporation . . . "big business." Yet it all started with a young man who concentrated all his efforts on what he could *contribute* . . . instead of thinking about how much money he could make.

It is significant that the last annual report of the company had John Deere's picture with the inscription —"He GAVE the world the steel plow."

That's what the world pays off for . . . *What you can GIVE IT.*

—"Success Secrets," Elmer Wheeler

* * *

All this happened to young Deere because he had an *idea* . . . and he *concentrated.*

That's a combination you can't beat . . . A man with an *idea* . . . who can *concentrate.*

YOU have an idea. You want to get ahead . . . through study. That's the Number One Ingredient in this invincible combination. Add to that idea, *concentration . . . and nothing can stop you!*

WALSCHAERT VALVE GEAR

PART 1

By

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Serial 4003A-3

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What This Text Covers . . .

1. Action of Gear and Principles Involved . . . Pages 1 to 12

The first part introduces the invention of the Walschaert valve gear, the underlying principles and individual characteristics. The general position of the valve in respect to piston and main crank is outlined. Arrangement for reversing, effect of lap and lead and arrangement for displacing them, and action of cranks are all discussed here.

2. General Description and Operation ..... Pages 13 to 22

Under these headings are listed the names of parts, and their operation. Details are given on movement imparted by reverse lever, general operation of gear, oiling points, and radius-rod connection with outside and inside admission valves, and different arrangements of gear.

3. Types of Gear Frames, Radius-Rod Hangers, and Reverse Shaft Cranks ..... Pages 23 to 27

Reasons for necessity of different types of gear frames, radius-rod hangers, and reserve-shaft cranks. Disadvantages are discussed and explanation made of the difference in thrust on link-trunnion bearings.

4. Eccentric Crank ..... Pages 28 to 33

These pages deal with the development, action and position of the eccentric crank. Details are given on direct and indirect motion, center line motion, condition on which piston depends, and outside and inside admission valves with direct and indirect motion.

4. Link Arc and Link Radius Valve Lead .... Pages 34 to 40

Comparison is made here with the variations of Walschaert valve gear and others in relation to link arc and radius. Constant lead, variable preadmission with constant lead, crossed lead and unequal valve travel are treated.

6. Radius Rod Movement and Valve Travel .. Pages 41 to 42

These two important features, radius rod movement and valve travel, are emphasized and a rule for changing the lead is explained.

7. Dimensions of Walschaert Valve Gear ... Pages 43 to 44

Special attention is called to sizes of important parts. Advantages of long valve travel and factors limiting valve travel are discussed.

WALSCHAERT VALVE GEAR

PART 1

ARRANGEMENT AND OPERATION

ACTION OF GEAR

INTRODUCTION

1. The Walschaert valve gear was invented by Edige Walschaerts in 1844. In naming the gear, the last letter of the name has been dropped. The gear, although used to a large extent in Continental Europe, was not applied to locomotives in America to any extent until about 1900, when locomotives had increased in size to such an extent as to make it impracticable to use a valve gear like the Stephenson, which is placed between the wheels. At the present time the Walschaert and other gears have entirely superseded the Stephenson gear on new locomotives.

The only valve gear that can be successfully applied to a modern locomotive is one that, like the Walschaert or some other gear similarly located, is placed outside of the frames. The reason an inside valve gear cannot be used on a modern locomotive is that the axles are so large as to require eccentrics and eccentric straps of too great a size. In addition, large locomotives require cross-bracing between the main frames and also between the frames and the boiler, so as to maintain alinement and stability and to reduce frame failures, and the bracing interferes with the application of an inside valve gear.

The advantages of the Walschaert valve gear over the Stephenson are that it is light, accessible for inspection and maintenance, and low in maintenance cost, and that it will keep square

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from shopping to shopping when once correctly set. The gear does not interfere with the proper bracing of the frames, which is most essential with heavy locomotives.

PRINCIPLES UNDERLYING GEAR

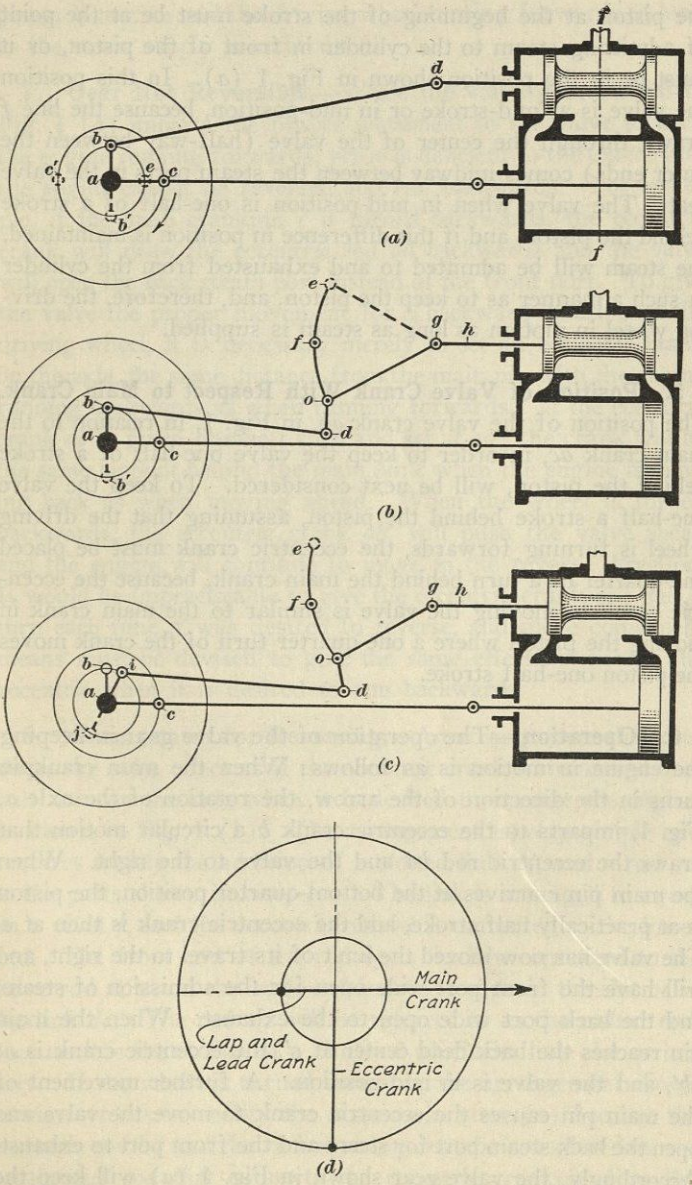
2. Characteristics of Walschaert Gear.—A characteristic of the Walschaert valve gear as compared with the Stephenson gear is that the former uses but one eccentric crank for both the forward and backward motions. The eccentric crank also has no angular advance, which means that it is set at approximately 90 degrees, or a quarter of a turn from the main crankpin. With the Stephenson gear the eccentrics have to be set to displace the valve the amount of the lap plus the lead from mid-position when the piston is at the beginning of the stroke.

3. Investigation of Principles.—An investigation of the principles underlying the arrangement and operation of the Walschaert valve gear will show why one eccentric crank can be used for both forward and backward motions, as well as the reason why the eccentric crank requires no angular advance.

Like any other device, the arrangement of the Walschaert valve gear can be traced back to some elementary type of gear of very simple design. Therefore, it is desirable when beginning an investigation of the principles on which the gear is based, to start with a simple gear and trace its development to one of the Walschaert type.

A simple form of valve gear is shown in Fig. 1 (*a*), and it will be explained how a gear can be evolved that will use but one eccentric crank *ab* with no angular advance for both forward and backward motions; *a* is the main axle, *ab* the eccentric crank for moving the valve through the eccentric rod *bd*, and *ac* is the main crank with the main pin *c*. The valve, that is inside admission, has no lap or lead; that is, the width of the valve between the steam and the exhaust edges is exactly the same as the width of the steam ports.

4. Position of Valve With Respect to Piston.—To start the piston moving when the wheel is given a slight turn in the direction of rotation, which, in this case, is forwards, the valve with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(c)
Main
Crank
Lap and
Lead Crank
Eccentric
Crank
(d)

FIG 1

the piston at the beginning of the stroke must be at the point of admitting steam to the cylinder in front of the piston, or it must be in the position shown in Fig. 1 (*a*). In this position the valve is at mid-stroke or in mid-position, because the line *f* drawn through the center of the valve (half-way between the outer ends) comes midway between the steam ports in the valve seat. The valve when in mid-position is one-half of a stroke behind the piston, and if this difference in position is maintained, the steam will be admitted to and exhausted from the cylinder in such a manner as to keep the piston, and, therefore, the driving wheel in motion as long as steam is supplied.

5. Position of Valve Crank With Respect to Main Crank. The position of the valve crank *ab*, in Fig. 1, in relation to the main crank *ac*, in order to keep the valve one-half of a stroke behind the piston, will be next considered. To keep the valve one-half a stroke behind the piston, assuming that the driving wheel is turning forwards, the eccentric crank must be placed one-quarter of a turn behind the main crank, because the eccentric crank in moving the valve is similar to the main crank in moving the piston where a one-quarter turn of the crank moves the piston one-half stroke.

6. Operation.—The operation of the valve gear in keeping the engine in motion is as follows: When the main crankpin turns in the direction of the arrow, the rotation of the axle *a*, Fig. 1, imparts to the eccentric crank *b* a circular motion that draws the eccentric rod *bd* and the valve to the right. When the main pin *c* arrives at the bottom-quarter position, the piston is at practically half stroke, and the eccentric crank is then at *e*. The valve has now moved the limit of its travel to the right, and will have the front port wide open for the admission of steam, and the back port wide open to the exhaust. When the main pin reaches the back dead center at *c'*, the eccentric crank is at *ab'*, and the valve is in mid-position. A further movement of the main pin causes the eccentric crank to move the valve and open the back steam port for steam and the front port to exhaust. Accordingly, the valve gear shown in Fig. 1 (*a*) will keep the

piston in motion and the driving wheel turning forwards so long as the steam supply is maintained.

7. Gear Not Reversible.—While the valve gear shown in Fig. 1 (*a*) imparts the proper movement to the valve to keep the engine running forwards, yet it is deficient to the extent that the engine cannot be reversed and run backwards. For example, if the main crankpin *c* is turned backwards, the eccentric crank will draw the eccentric rod *bd* backwards and the valve will open the back steam port instead of the front port. To give the valve the proper movement for a backward rotation of the driving wheel, it is necessary merely to set an eccentric crank on the axle, the same distance from the main pin with the engine running backwards as when running forwards. If the eccentric crank *ab* is given one-half turn and set at *ab'*, the crank will be the same amount behind the main pin *c* when the engine is moving back as when moving ahead. When the wheel is turned backwards, the eccentric crank *ab'* will push the valve ahead and the engine will continue to move in the reverse direction. It would be impracticable to give the eccentric crank one-half a turn each time it was desired to reverse, and more convenient means must be devised to give the same effect as moving the eccentric when it is desired to run backwards.

8. Arrangement for Reversing.—An arrangement that produces the same effect as if the eccentric crank were moved one-half turn on the axle when it is desired to reverse the engine, is shown in Fig. 1 (*b*). The arrangement is very simple and requires merely the addition of a slotted link *ed*, and a rod *go*, to the parts shown in view (*a*). The link is arranged to swing on a pivot *f*, and the eccentric rod *bd* is connected to the lower end. The front end of the rod *og* is flexibly connected to the valve rod at *g* and the back end is free to slide in the slot *oe* in the link *de*. The rod *og* will be referred to as the *radius rod*, because it is the radius of a circle of which the link slot *oe* is a part. If the wheel is turned forwards, the arrangement shown in view (*b*) is in reality the same as in view (*a*) because the eccentric rod *bd* and the radius rod *og* may be considered as one continuous rod that connects the eccentric crankpin *b* to the

valve stem *gh*. To reverse, it is only necessary to raise the radius rod *og* to *ge*. Then when the main pin *c* is turned in the reverse direction, the eccentric crankpin *b* moves the eccentric rod and the bottom of the link backwards, and as the link pivots at *f*, the upper end *e* of the link, the radius rod *ge* and the valve move forwards or to the right. When the valve moves to the right, the steam enters the cylinder through the front steam port and the engine will continue to run backwards.

9. By the use of a link *ed*, Fig. 1 (*b*), with a fulcrum at the middle, the same movement is imparted to the valve as if the eccentric were given one-half turn and moved from *b* to *b'*. In other words, the effect of moving the radius rod to the upper end of the link is precisely the same as if the rod were left at *go* and the eccentric crank were moved to *b'*, a distance of one-half turn. Therefore, when it is desired, as in this case, to develop a valve gear with but one eccentric crank for both motions, a link arranged as shown in view (*b*) forms a convenient means of reversing, for the reason that it makes one eccentric perform the work of two.

10. Effect of Lap and Lead on Arrangement.—A steam engine cannot be operated economically unless provision is made for moving the piston by the expansive force of steam, and this can be done only by giving the valve steam lap. The steam lap makes the valve wider than the steam port and, therefore, introduces an interval between cut-off and release, instead of these valve events occurring simultaneously as in Fig. 1 (*a*) and (*b*), and during this interval the steam expands in the cylinder and moves the piston. The effect on the arrangement in view (*b*) when the valve is given lap and lead, will be considered next. The changes in the valve gear when lap and lead is given will be seen by referring to Fig. 1 (*c*).

In view (*c*) the same parts are used as in view (*b*), but the valve has been given steam lap and lead. This requires the eccentric to be moved away from its right-angle position at *ab* to *ai* in order to displace the valve from mid-position the amount of the lap and lead and so have the front steam port open when the piston is at the end of the forward stroke. The reason is if

the position of the eccentric crank were not changed, the valve would be in mid-position with the piston at the end of either stroke. In this event the steam edges of both ports would be blanked the amount of the steam lap, and steam would not be admitted to the cylinder until the piston had moved some distance on its stroke. The change in the position of the eccentric pulls the link *de* out of the position shown in view (*b*) to the position shown in view (*c*).

11. The arrangement in Fig. 1 (*c*) will cause the valve to operate properly so long as the engine is moving forwards, but will not permit the motion to be reversed, for the following reason: If the radius rod is moved from *go* to the top of the link, the effect, as already explained, is the same as if the eccentric crank *ai* were given one-half a turn which, in this case, would bring it to *aj*. The valve, instead of being the amount of the lap and the lead to the right of the mid-position with the eccentric at *ai*, is now the amount of the lap and lead to the left of its mid-position, and hence will open the back steam port to steam. The piston cannot move backwards because it is blocked by the steam behind it.

12. In Fig. 1 (*b*) the eccentric crank *ab'* must be the same distance behind the main pin *c* when the engine is running backwards as the crank *ab* is behind the main pin with the engine running forwards. The effect of moving the radius rod from *go* to *ge* is the same as if the eccentric crank were given one-half turn from *ab* to *ab'*. It is only when the eccentric crank and the main crank are at right angles to each other that the eccentric crank, when given one-half turn, will still be the same distance from the main crank. For example, with the eccentric crank set at *ai*, view (*c*), the effect when the engine is reversed is to give the eccentric crank *ai* one-half a turn to *aj*, and the crank at *aj* is farther from the main crank *ac* than at *ai*.

The foregoing shows that when one eccentric is used for both motions, it cannot be given angular advance or moved to displace the valve, the lap and the lead, because if it is, the engine cannot be reversed. Therefore, the right-angle setting of the eccentric crank must be adhered to, as shown in (*b*), and some other

means must be found to obtain the lap-and-lead displacement of the valve.

13. Arrangement for Displacing Valve Lap and Lead. The right-angle setting of the eccentric crank can be adhered to and the lap-and-lead displacement of the valve with the engine on the dead center can be obtained theoretically by the use of another crank set at right angles to the eccentric crank. Thus, in Fig. 1 (*d*), the lap-and-lead crank, with a throw equal to the lap and the lead is set 90 degrees ahead of the eccentric crank with the locomotive moving forwards, and 180 degrees from the main crankpin, the valve being outside admission. Let it now be

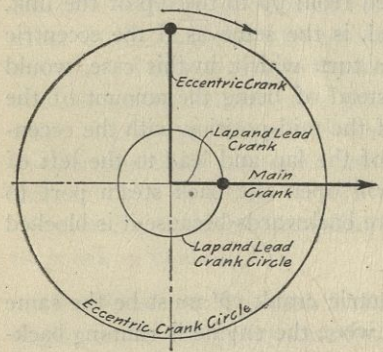


FIG. 2

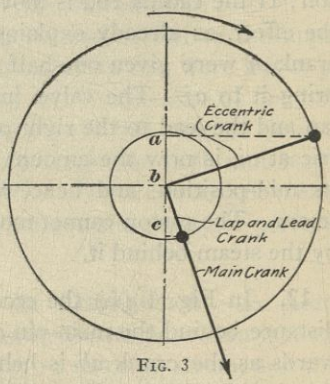


FIG. 3

assumed that the two cranks are both connected to the valve by some mechanism that duplicates the action of the actual gear. The position of the lap-and-lead crank displaces the valve from its mid-position an amount equal to the lap and the lead; then the front steam port will have the required lead opening. When the main crankpin has made one-half turn, the lap-and-lead crank will have displaced the valve the required amount to obtain the lead opening at the back port.

14. With an inside admission valve, Fig. 2, the lap-and-lead crank must be set 90 degrees in advance of the eccentric crank with the locomotive moving forwards. However, as the eccentric crank in this case is assumed to follow the main crankpin, the lap-and-lead crank will be at no angle to the main crank

instead of being at an angle of 180 degrees from it as with an outside admission valve.

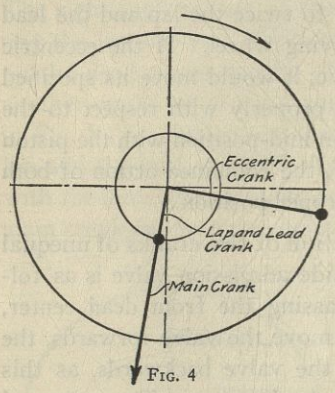
15. If the lap-and-lead crank was alone acting on the valve, its movement would be equal only to twice the lap and the lead for each one-half turn of the driving wheel. If the eccentric crank was alone acting on the valve, it would move its specified travel, but it would not be timed properly with respect to the piston, that is, the valve would be in mid-position with the piston at the end of its stroke. However, the combined action of both cranks will bring the valve to its proper position.

16. Action of Cranks.—The action of two cranks of unequal length on the movement of an inside admission valve is as follows: With the main crankpin passing the front dead center, Fig. 2, the eccentric crank acts to move the valve forwards, the lap-and-lead crank tends to pull the valve backwards, as this crank is now leaving its forward dead center. The action of the longer crank predominates but the forward movement of the valve is retarded by the lap-and-lead crank. This action continues until about full port opening is obtained or until the cranks arrive in the position shown in Fig. 3. At this point the valve stops because the action of the eccentric crank is now equal to a crank of a length *ab*, which in turn is equal to the length of the equivalent lap-and-lead crank *bc*. Hence, the eccentric crank is now moving the valve ahead at the same rate as the other crank is moving the valve back. Also, the valve is moving slowly when the cranks are approaching and leaving these points.

17. In Fig. 4 both cranks are acting on the valve to draw it backwards and close the front steam port and this action continues until the cranks assume the position shown in Fig. 5. The eccentric crank in the absence of the lap-and-lead crank would place the valve in mid-position, but with this crank acting with the eccentric crank the speed of the valve is increased, and this combined with the setting of the lap-and-lead crank places the valve one lap plus one lead from mid-position with the crankpin on the center.

The action of the cranks on the valve as the main crankpin passes the back center is similar to their action when the

crankpin passes the forward center; that is, the eccentric crank is moving the valve back to open the back steam port farther and the lap-and-lead crank is delaying this movement. This action



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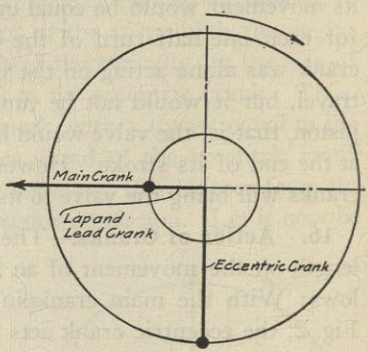
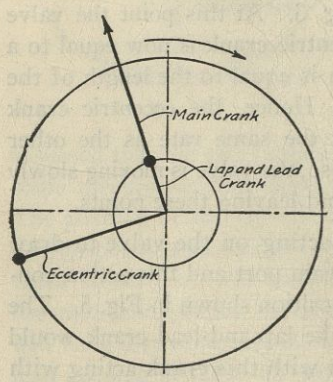


FIG. 5

continues until the cranks arrive in the position shown in Fig. 6. The valve now stops momentarily for the same reason as given when considering Fig. 3; that is, the action of the eccentric



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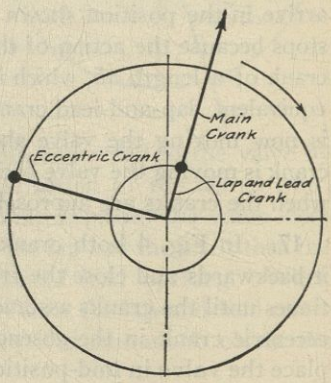


FIG. 7

crank on the valve is now equal to that of the lap-and-lead crank, owing to their effective crank lengths being the same in this position.

In Fig. 7, both cranks are acting on the valve, its velocity is thereby increased to such an extent that the valve is displaced,

an amount equal to its lap and lead, from mid-position with the crankpin on the forward dead center and the piston at the end of its stroke. It will be noted that the action of the cranks causes the port to open slowly for the admission of steam but to close rapidly. In order that the cranks may increase the speed of the valve when they are both operating together, it must be assumed that the two cranks are connected to the valve in such a manner as to cause them to act on it independently of each other. Then when so connected the valve will have a higher speed when the cranks are working together than when working in opposition.

18. If the eccentric crank were shortened, this giving in combination with the other crank an effect equivalent to hooking up the actual gear, the valve travel would be shortened, but the action of the lap-and-lead crank would be the same; that is, it would still act to vary the speed of the valve. With the eccentric crank shortened to less than the lap-and-lead crank, the latter crank would limit the valve travel to double the lap and the lead; the eccentric crank would then act to vary the valve speed. If the length of the eccentric crank were decreased to zero the total valve travel would still be obtained from the lap-and-lead crank. It will be noted, after the eccentric crank has been shortened to less than the lap-and-lead crank, that any further shortening does not affect the valve travel; it remains equal to that imparted by the lap-and-lead crank.

19. It would be difficult or probably impossible to design the necessary mechanism to connect the eccentric crank and the lap-and-lead crank to the valve. However, it is possible to use the main crank for a lap-and-lead crank, provided the movement of the main crank or the crosshead, because they both move together, is reduced to the proper amount. This is accomplished by means of a lever known as the lap-and-lead lever, or the combination lever, with one end connected to the crosshead at *l*, Fig. 8, and its upper end connected to the radius rod at *m*. The reduction in the movement of the crosshead or the main crank to twice the lap-and-lead movement is brought about by connecting the valve rod to the lever at the point *g'*. This point

is so located between the ends of the lever that the crosshead movement at the lower end of the lever is reduced to a movement equal to twice the throw of the lap-and-lead crank at the valve rod. With the point m held fixed, the movement of the crosshead and the lower end of the lever from l to l' moves the valve from g' to g, or twice the lap and the lead.

20. The arrangement of the eccentric crank and the combination lever will produce practically the same action on the valve as the two cranks already described. That is, as the combination lever replaces the lap-and-lead crank, this lever, except as explained below, varies the speed of the valve and causes it to be displaced, its lap and lead from mid-position with the

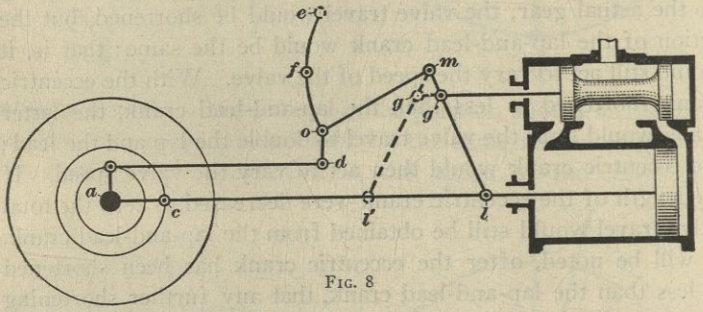
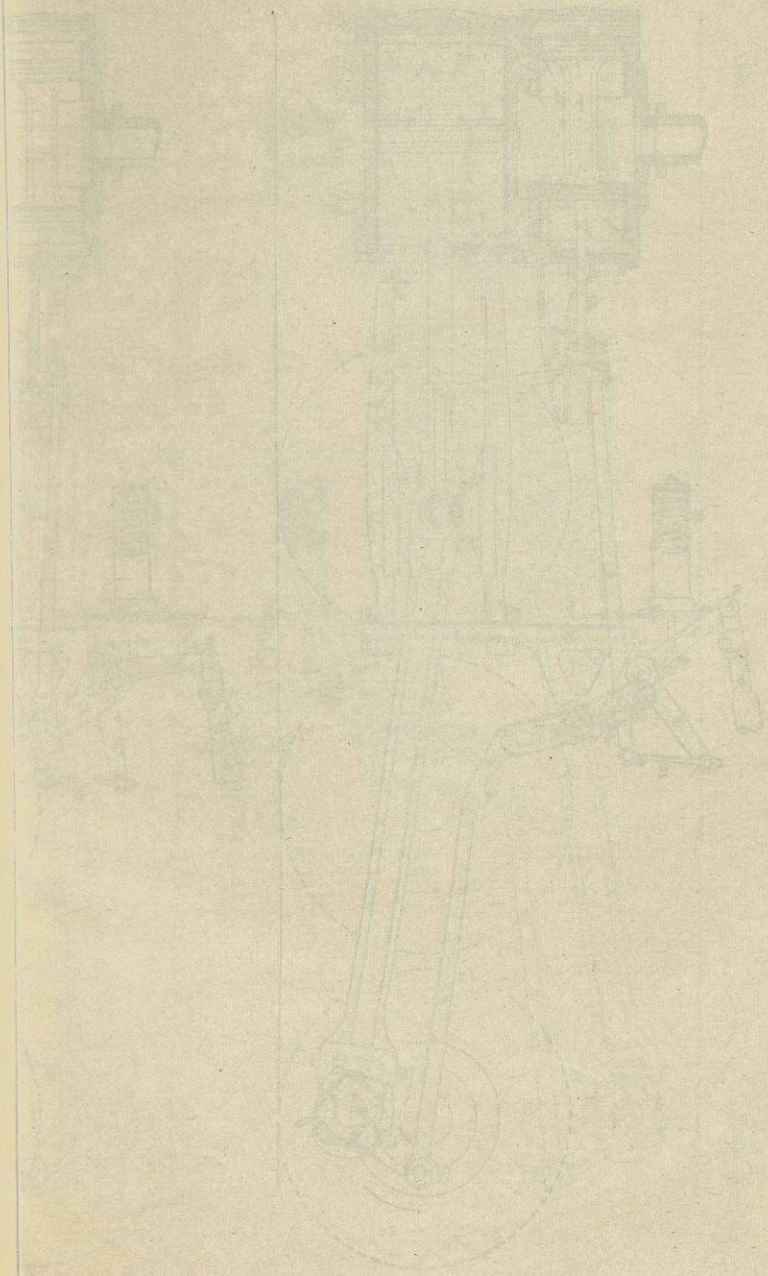
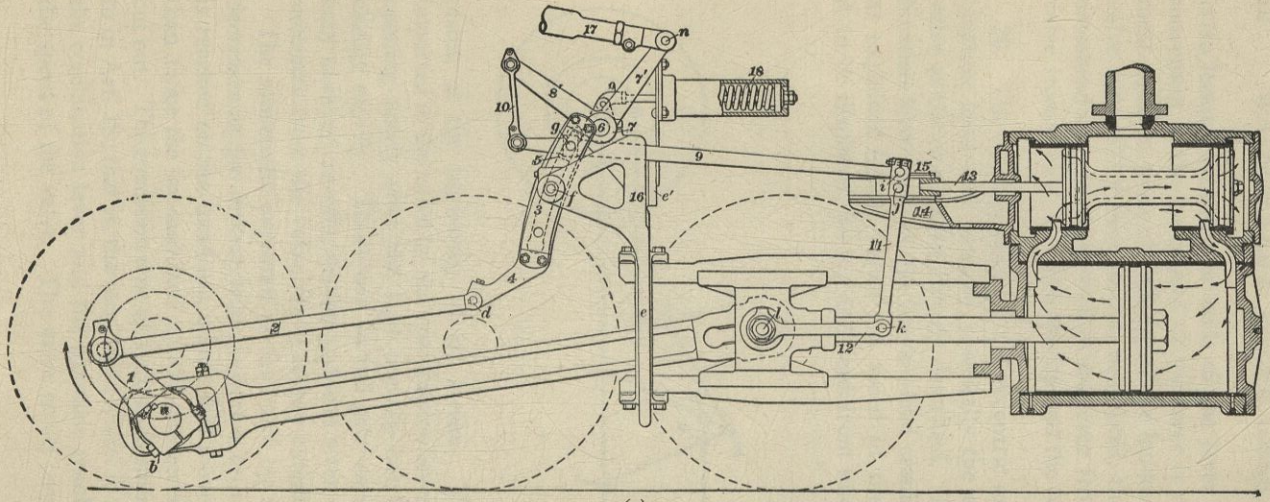


FIG. 8

piston at the beginning of its stroke. The variable speed imparted to the valve by the combination lever results in the port opening slowly after the lead opening has been obtained, and closing rapidly. Therefore, in full gear as well as in the ordinary working cut-offs, the lap-and-lead lever neither adds to nor subtracts from the valve travel to any extent.

The movement imparted to the valve by the eccentric crank decreases as the reverse lever is drawn up until finally a point is reached on the quadrant where this movement becomes less than twice the lap-and-lead travel; the eccentric crank is then cut out. The condition that now exists is similar to that referred to in Art. 18; that is, the total valve travel is then obtained from the combination lever and the eccentric crank acts only to vary the speed of the valve. The valve travel now remains the same

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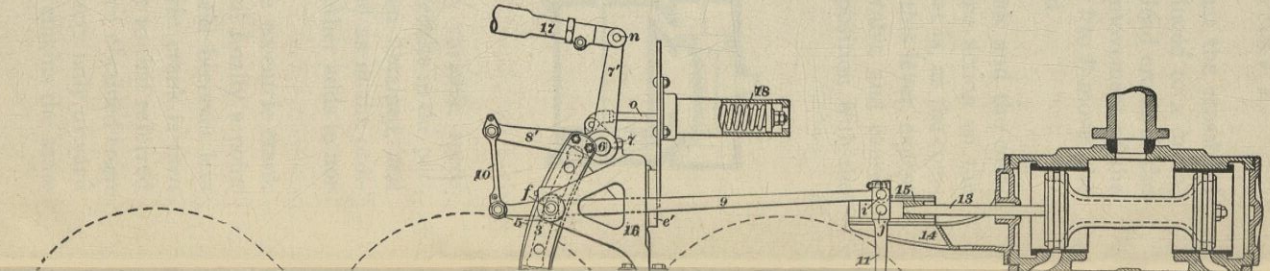
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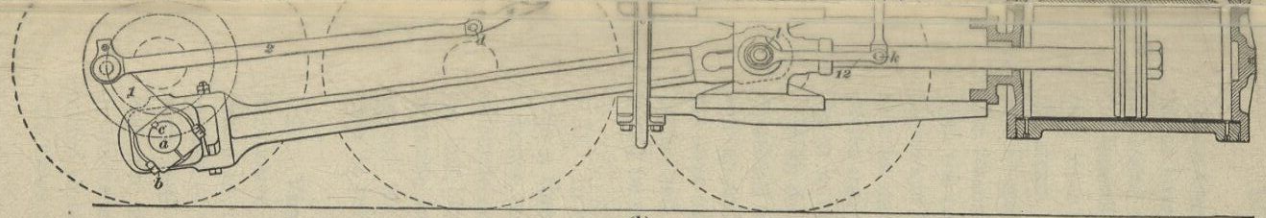

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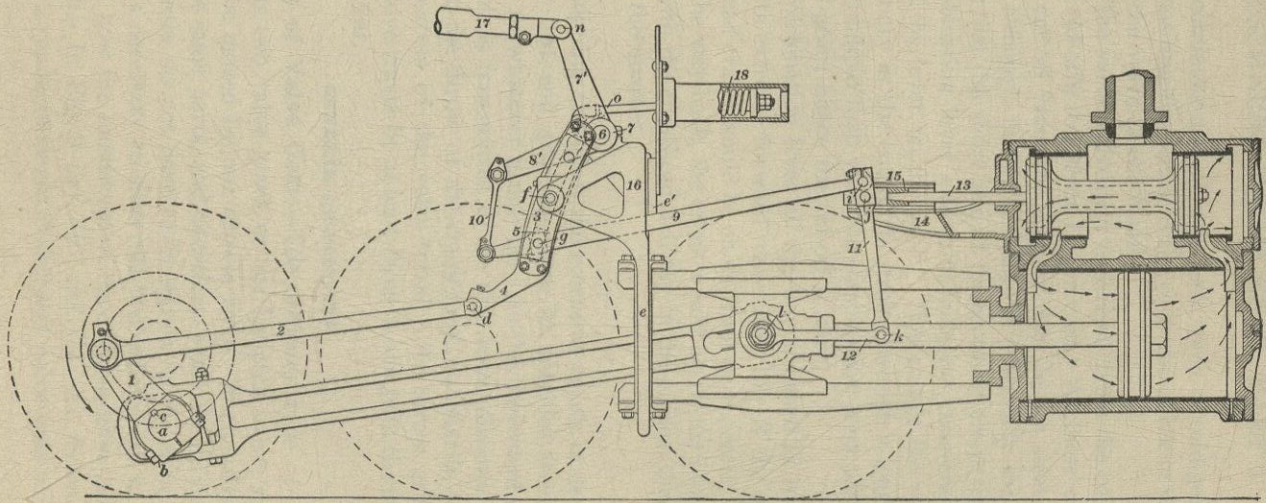

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FIG. 9

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as the lever continues to be drawn back, even to mid-gear, but in the latter position the action of the eccentric crank in varying the speed of the valve is eliminated.

Generally, the valve movement is derived from the combination lever at cut-offs less than 15 per cent. At these cut-offs the steam is cut off from the cylinder later in the stroke than in mid-gear, although the valve travel is practically the same. The reason is that the short arm of the eccentric crank that acts with the combination lever except in mid-gear counteracts the movement of the lever on the valve. This causes the valve to remain stationary at the end of its stroke through a longer arc of the main crankpin than with the combination lever alone acting as in mid-gear; hence the cut-off is later.

With the combination lever all the way forward as with the crosshead at its extreme forward movement, Fig. 8, the equivalent lap-and-lead crank would be on its front dead center. With the lever all the way back, the crank would be on the back dead center, and, with the crosshead halfway in the guides, the crank would be on the quarter.

21. In designing the gear, the eccentric crank is designed with a throw that will give the valve its specified travel, $7\frac{1}{2}$, 8 inches, etc., or whatever it may be. As the movement of the eccentric crank is transmitted to the link some distance below the link block, the throw of the crank must necessarily be considerable in excess of the valve travel. Its throw generally exceeds the valve travel by at least three to one with the reverse lever in full gear.

GENERAL DESCRIPTION

22. **Views of Valve Gear.**—The ordinary type of steam locomotive has two valve gears, or one for each valve, so connected as to be moved by one reverse lever. Each valve gear consists of the same parts, and, therefore, when identifying the parts, both gears do not have to be shown in the same view. However, it is necessary to show the two valve gears in order to understand how the movement of the reverse lever is transmitted to both. In Fig. 9 (*a*), (*b*), and (*c*), are shown three side views of a complete single Walschaert valve gear when an

inside-admission valve is used, and Fig. 10 is a partial view which shows how the connection is made between the gears on each side so that the movement of the reverse lever and the reach rod can be transmitted to both. Similar parts in all of the views have the same reference figures.

23. Names of Parts.—The names of the parts of the gear shown in Fig. 9 are as follows: *1*, the eccentric crank; *2*, the eccentric rod; *3*, the link with the link foot *4*; *5*, the link block; *6*, Figs. 9 and 10, the reverse shaft; *7*, the reverse-shaft crank with arms *7'* and *8'*; *8*, Fig. 10, the reverse-shaft arm; *9*, Fig. 9, the radius rod or radius bar; *10*, the radius-rod hanger; *11*, the combination lever, combining lever, or lap-and-lead lever; *12*, the union link; *13*, the valve stem; *14*, the valve-stem crosshead guide; *15*, the valve-stem crosshead; *16*, the gear frame or the link support here shown cast with the guide yoke; *17*, the reach rod; *18*, the counterbalance spring and casing. The valve gear is shown in forward gear in Fig. 9 (*a*), in mid-gear in (*b*), and in backward gear in (*c*).

24. General Arrangement of Parts.—The general arrangement of the parts of the Walschaert valve gear will be explained by referring to Fig. 9. A detailed explanation of the arrangement and construction at the different points in the gear will be given further on.

The eccentric crank *1* is placed on the end of the main crankpin *a*. The bolt *b*, which passes through the eccentric crank, and a circular slot in the side of the crankpin, keeps the crank from coming off the pin, and the key *c* prevents the crank from turning on the pin. The rear end of the eccentric rod is placed on a pin in the eccentric crank which is usually made in one piece with the crank and stands at right angles to it. The front end of the eccentric rod is forked and is connected to the link foot *4* by the pin *d*. The gear frame *16* is here shown as being made in one piece with the guide yoke *e*, but it is usually made separate. The guide yoke is bolted to the end of a cross-tie *e'*, which extends across the frames to the other side and serves as a support for the other combined yoke and gear frame. A bracket or knee is bolted to each frame at the point where the cross-tie

crosses it and the cross-tie is bolted to this knee. The link *3* is carried in the gear frame on the link trunnions *f* (one on each side). The radius rod *9* is forked where it passes through the link, and the link block *5* sets between the forks and is held in the rod by the link-block pin *g*. The link block *5*, which moves in a slot in the link, shown by dash lines, when the radius rod is raised and lowered, is used to transmit the backward-and-forward movement of the link to the radius rod. The rear end of the radius rod swings on the radius-rod hanger *10* which is connected at the upper end to the arm *8′* of the reverse-shaft crank, while the front end of the rod is connected by the pin *i* to the top of the combination lever *11*. The connection between the valve-stem cross-head *15* and the combination lever *11* is made by the pin *j* and the lower end of the lever is connected to the union link *12* by the pin *k*. The back end of the union link works freely on the outer end of the wristpin *l*. The valve-stem crosshead guide *14* is cast in one piece with the back-valve chamber head and the valve stem *13* is connected to the crosshead *15* by a key, not shown. The end of the reach rod *17* is forked and is connected to the arm of the reverse-shaft crank *7′* by a pin *n*.

25. The valve gear on each side of the locomotive is connected by the reverse shaft *6*, Fig. 10, which turns in boxes *d* on the gear frames when the reverse lever is moved. The reverse-shaft crank *7*, made in one piece, is keyed or bolted to one end of the reverse shaft, and the reverse-shaft arm *8* to the other end. The two reverse-shaft arms *8* and *8′* are connected by the radius-rod hangers *10* to the radius rods *9*; hence, when the reverse lever is moved, the reach rod *17* through its connection with the reverse-shaft crank *7*, turns the reverse shaft *6*, and, depending on the direction of movement, raises or lowers the arms *8* and *8′* and the radius rods *9*. The combined guide yoke and gear frame *16* bolts at the points *m* to the rectangular plate or casting *e′*, Fig. 9, which extends across and is connected to the frames by brackets. Strictly speaking, the casting *e′* is the guide yoke, and the part *16* is the gear frame and guide-yoke end. The purpose of the counterbalance spring *18*, Fig. 9, which is connected to the reverse shaft *6*,

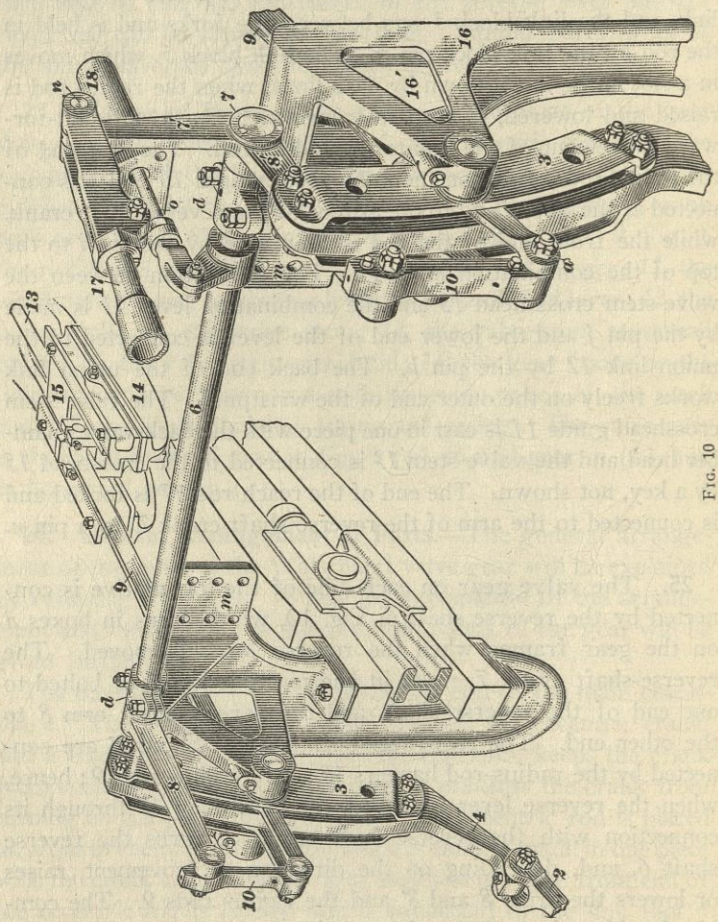


FIG. 10

Fig. 10, by an arm and a rod *o*, is to make it easier to move the reverse lever against the weight and friction of the valve gear. The spring *18*, Fig. 9 (*c*), is compressed when the radius rods are lowered to the bottom of the links, hence the expansion of the spring helps to lift the rods to the top of the links as shown in view (*a*).

26. A complete locomotive valve gear, by which is meant the two gears a part of which is shown in Fig. 10, may be considered as made up of two parts. One part is directly concerned with valve movement and is in operation when the locomotive is in motion, while the other part is used to transmit movement to the first part through the reverse lever. The eccentric cranks, the eccentric rods, the links, the link blocks, the radius rods, and the combination levers, there being two of each of the above, are the parts of the gear which have to do with moving the valves. The other part of the gear comprises the two radius-rod hangers, the reverse-shaft crank, the reverse-shaft arm, and the reverse shaft. These parts are used to transmit the movement of the reverse lever equally to the valve gear on each side of the locomotive.

GENERAL OPERATION

27. Movement Imparted By Reverse Lever.—Any movement of the reverse lever changes the position of the link blocks and radius bars in the links. The action that occurs when the reverse lever is moved is as follows: In Figs. 9 (*b*) and 10, when the reverse lever and the reach rod *17* are moved forwards, the reverse-shaft crank arm *7′* moves in the same direction and turns the reverse shaft *6*. The reverse-shaft arms *8* and *8′*, Fig. 10, move upwards and the radius-rod hangers *10*, the radius rods *9* and the link blocks are raised to the position shown in Fig. 9 (*a*). Therefore, in this case, the link blocks are in the upper half of the links, in forward gear. When the reverse lever, Figs. 9 (*b*) and 10, is moved from the front to the back corner of the quadrant, the reverse-shaft crank *7* turns the reverse shaft *6* and the downward movement of the reverse-shaft arms *8* and *8′* lowers the radius-rod hangers, the radius rods, and the link blocks to the lower half of the links. The

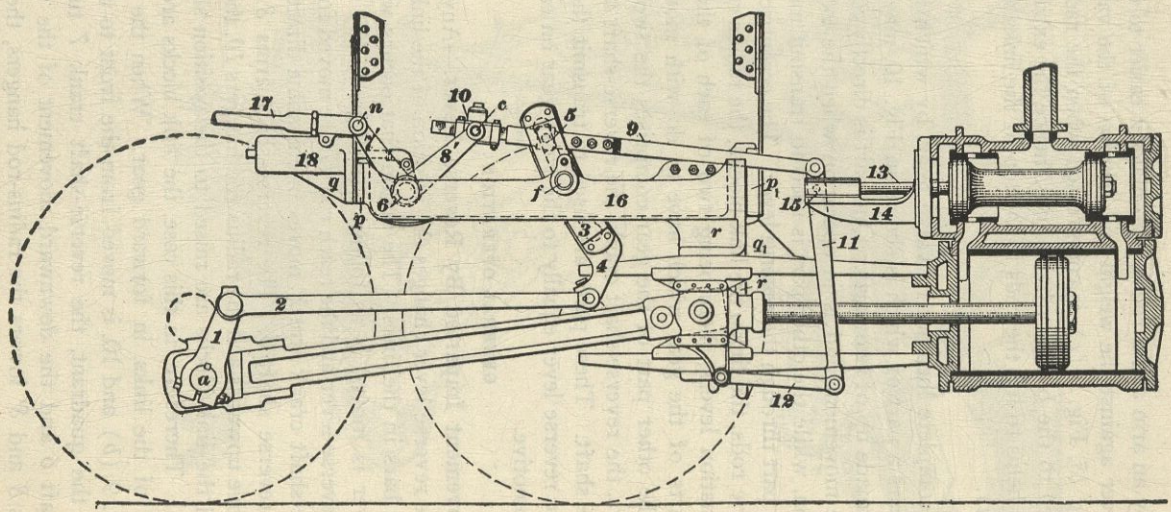


FIG. 11

extent of the valve movement when the reverse lever is moved depends on the position of the main pins. With the main crank-pin *a* on the bottom quarter, moving the reverse lever from the

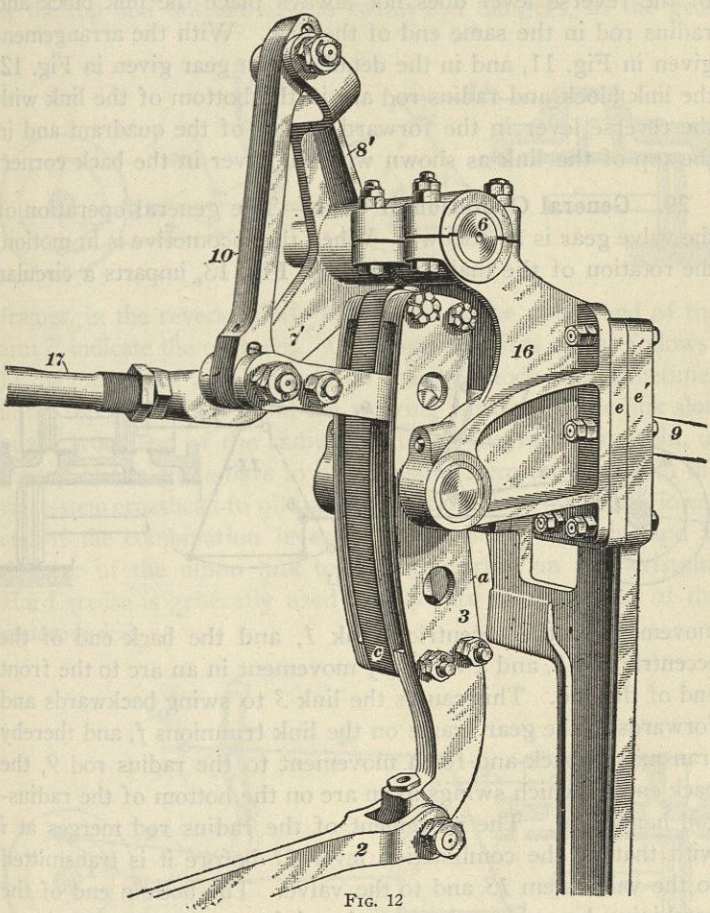


FIG. 12

front to the back corner of the quadrant causes the valve to close the front steam port and open the back steam port.

28. The cut-off is longest with the link blocks in the ends of the links and decreases as the blocks are brought nearer to the center of the links. With the link blocks in the center of

the links, the port opening obtained with the engine on the dead centers is equal to the lead. The valve begins to close the port as soon as the main pin leaves the dead center. The movement of the reverse lever does not always place the link block and radius rod in the same end of the link. With the arrangement given in Fig. 11, and in the detail of the gear given in Fig. 12, the link block and radius rod are in the bottom of the link with the reverse lever in the forward corner of the quadrant and in the top of the link as shown with the lever in the back corner.

29. General Operation of Gear.—The general operation of the valve gear is as follows: When the locomotive is in motion, the rotation of the main crankpin *a*, Fig. 13, imparts a circular

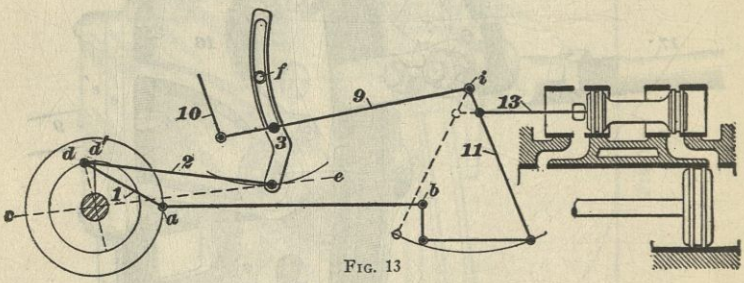


FIG. 13

movement to the eccentric crank *1*, and the back end of the eccentric rod *2*, and a vibratory movement in an arc to the front end of the rod. This causes the link *3* to swing backwards and forwards in the gear frame on the link trunnions *f*, and thereby transmits a back-and-forth movement to the radius rod *9*, the back end of which swings in an arc on the bottom of the radius-rod hanger *10*. The movement of the radius rod merges at *i* with that of the combination lever *11* before it is transmitted to the valve stem *13* and to the valve. The bottom end of the combining lever has a backward and forward movement, in an arc, and this, when transmitted to the top of the lever in combination with the action of the radius rod at this point, imparts the required movement to the valve to keep the locomotive in operation. The combination lever acts on the valve in opposition to the crank when passing dead centers.

30. **Oiling Points in Valve Gear.**—The eccentric-rod pin in the front end of the eccentric rod is oiled through the oil cup shown on the link foot, Fig. 9. In Fig. 10, black circular marks at the top and bottom of the radius-rod hangers, in the gear

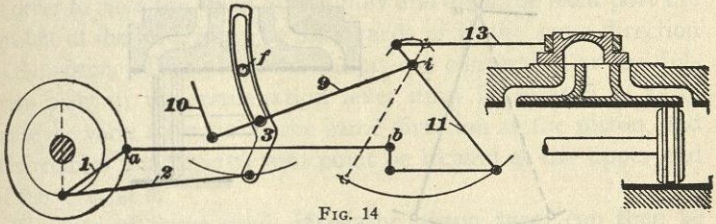


FIG. 14

frames, in the reverse-shaft boxes and in the upper end of the arm 7′ indicate the oil holes. Other oiling points are as follows: In the top of the link block to oil the link-block pin, sometimes in the top of the link to oil the wearing surface of the link slot, in the front end of the radius rod to oil the radius-rod pin, in the top of the guide bars to oil the valve-stem crosshead, in the valve-stem crosshead to oil the combination-lever pin, in the lower end of the combination lever to oil the union-link pin, and at the rear of the union link to oil the bearing on the wristpin. Hard grease is generally used to lubricate the back end of the eccentric rod.

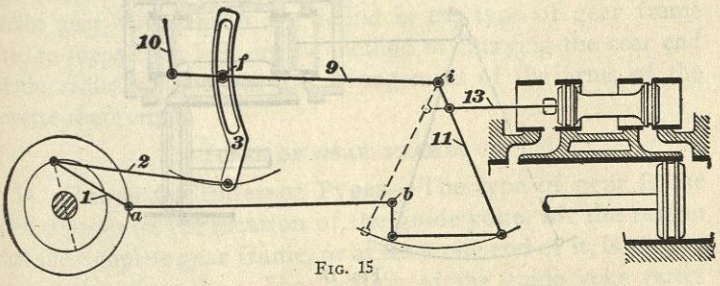


FIG. 15

31. **Location of Radius-Rod Connection With Outside- and Inside-Admission Valves.**—The radius rod is not connected to the combining lever at the same point with an outside-admission valve as with an inside-admission valve. In Fig. 14, with

an outside-admission valve, the radius rod *9* is connected to the combination lever *11* at *i* between the ends, and with an inside-admission valve, Fig. 15, the connection is made at the

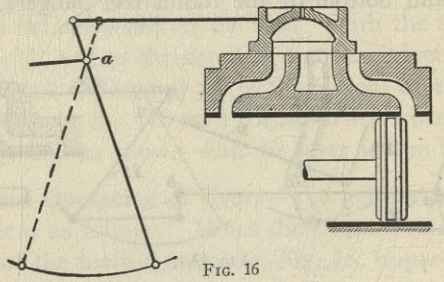


FIG. 16

upper end. The reason is that an outside-admission valve during the lap-and-lead movement, moves in the direction opposite to the piston, while an inside-admission valve moves in the same direction; therefore, the radius-rod connection, which acts as a fulcrum or fixed point, must be located accordingly. It will be noted that the lap-and-lead movement refers to the movement of the valve from the lead opening at one port to the lead opening at the other port.

In Fig. 16, when the piston moves from the front to the back end of the cylinder, the total movement of the valve has to

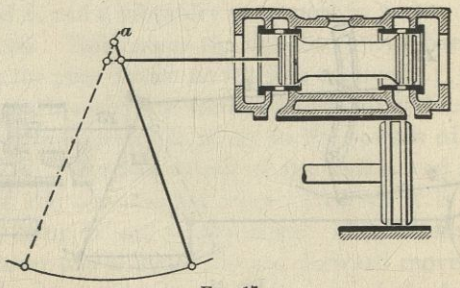


FIG. 17

be forwards or in a direction opposite to that of the piston in order to close the front steam port, and to open the back port the amount of the lead. Therefore, the fulcrum or fixed point of the combination lever must be between the ends, or at *a*, so

as to cause the movement at the bottom of the lever to be converted into a movement in the reverse direction at the top.

32. In Fig. 17 with an inside-admission valve and the piston making the same movement, the whole movement of the valve, in order to close the front steam port and open the back port the amount of the lead, must be backwards or in the same direction as the piston. Therefore, the radius-rod connection or the fulcrum point of the combination lever must be located so as to cause the valve to move in the same direction as the piston, and this requires that the fulcrum point be located at the upper end of the lever at *a*.

The kind of valve used, if of the piston type, can then be identified by observing where the radius rod is connected to the combining lever. If between the ends, the valve is outside admission; if at the end, the valve is inside admission. A slide valve that is always outside admission can be readily identified by the shape of the steam chest.

DIFFERENT ARRANGEMENTS OF GEAR

33. There is very little difference in the arrangement of the Stephenson valve gear as applied to locomotives of different types. This does not apply to the Walschaert gear, as at certain points the design of the valve gear is influenced by the type and construction of the locomotive. The principal variations in the gear arrangement are found in the type of gear frame used to support the link, in the method of carrying the rear end of the radius rod, and in the arrangement of the arms of the reverse-shaft crank.

TYPES OF GEAR FRAMES

34. **Reason for Different Types.**—The type of gear frame used depends on the location of the guide yoke, for the reason that the complete gear frame, or at least one end of it, is always connected to the yoke. The location of the guide yoke varies because it has to be connected to the main frame of the engine, and hence must be placed at a point where the frame can be reached without interference from the driving wheel, and this fixes its position either in front or back of the first driving wheel.

When a locomotive has a two-wheel engine truck, the first driving wheel is so close to the cylinder that the guide yoke has to be placed at the extreme rear of the guide bars in order to clear the wheel and connect to the frame. In this case the type of gear frame shown in Fig. 9 is generally used because the guide yoke is far enough from the steam chest to permit a proper design of the parts of the gear forward of the yoke.

When a locomotive has a four-wheel truck, the rear-truck wheel is almost entirely behind the cylinder, and this brings the first driving wheel between the rear of the guide bars and the main frame. For that reason the guide yoke has to be placed ahead of the first driving wheel and quite close to the steam chest in order to connect to the frame. In this event the type of the gear frame shown in Fig. 9 cannot be used because the frame is too close to the steam chest to permit the valve gear to be properly designed. To bring the link about the same distance from the steam chest as before and thereby proportion properly the valve gear, the type of gear frame *16* shown in Fig. 11 is used. With this type of frame, the front end is bolted to the guide yoke p_1 to which the guide-yoke end r is also connected. The guide yoke is connected to the frame by the bracket q_1. The back end of the frame is connected to a cross-tie p laid across and connected to the main frames by a bracket q and extending far enough on each side to permit the gear frames to be connected to the outer ends. The link *3* is placed in the gear frame about midway between the ends. Therefore, the type of gear frame used depends largely on whether the engine has a two-wheel or a four-wheel engine truck.

TYPES OF RADIUS-ROD HANGERS

35. There are two ways of connecting the back end of the radius rod to the reverse-shaft crank, either by a hanger or by a radius rod lifter of the slip-block type. In Figs. 9 and 12 the radius rod *9* is connected to the arm *8′* of the reverse-shaft crank by a hanger *10*, and in Fig. 11 the rear end of the rod slides in a block *10* pivoted between the two arms *8′* of the reverse-shaft crank. One of these arms only can be seen, as the other lies directly behind it. The hanger arrangement is

in more general use because the arrangement shown in Fig. 11, being made of four parts, is difficult to maintain. The slip-block confines the end of the radius rod and the link block to a straight-line movement.

TYPES OF REVERSE-SHAFT CRANKS

36. **Arrangement of Crank.**—Unlike the Stephenson valve gear in which the link block is always in the upper part of the link in forward gear, the link block of the Walschaert gear, depending on the arrangement of the reverse-shaft crank may be in either the upper or the lower part of the link when the locomotive is running forwards. The link block and the radius rod may be in the upper part of the link in forward gear and in the bottom part in backward gear, as shown in Fig. 9; or, as shown in Figs. 11 and 12, these parts may be in the bottom of the link in forward gear and in the top of the link in backward gear. However, as with any type of locomotive valve gear, the locomotive runs forwards with the reverse lever in any position forward of the center notch of the quadrant, and backwards with the lever anywhere back of the center notch.

37. The position of the link block and the radius bar at the link depends on the arrangement of the reverse-shaft crank. In Fig. 9 the reverse-shaft crank arm *7'*, to which the reach rod connects, points upwards and a forward movement of the reverse lever and the reach rod places the link blocks and the back portion of the radius rods in the upper half of the links for forward gear as shown in Fig. 9 (*a*), while a backward movement of the lever beyond the center notch of the quadrant places these parts in the lower half of the links for backward gear as shown in view (*c*). In Fig. 12, the crank arm *7'* to which the reach rod is connected, points downwards, and when the reverse lever and the reach rod *17* are moved far enough ahead, the link block and the back end of the radius rod *9* move to the lower half of the link for forward gear, and to the upper half of the link as shown when the reverse lever is moved to the back part of the quadrant. With the reverse lever in the center of the quadrant, the link block and the radius bar are in the center of the link in both arrangements.

38. As will be fully explained later, the arrangement shown in Figs. 11 and 12 is to be preferred to that shown in Fig. 9. The reason for using the arrangement in Fig. 9 is that it is generally more convenient to connect the reach rod to an arm of the reverse-shaft crank which points upwards than to one which points downwards, as the connections at the power reverse gear and the crank arm are then more nearly in line.

The operation of the valve gear with the link block in the upper half of the link is confined generally to the type of gear frame shown in Fig. 9. With the type of gear frame shown in Fig. 11, the arm 7′ of the reverse-shaft crank to which the reach rod connects is more directly in line with the power-reverse gear when pointing upwards, and this places the link block in the lower part of the link in forward gear.

39. **Disadvantages.**—In road service where locomotives run mostly forwards, there are certain disadvantages connected with the operation of the gear when designed to work with the link block in the upper half of the link when the locomotive is running ahead. With switch engines, the position of the link block is immaterial, because these engines are worked as much in one gear as another. The disadvantages of having the link block in the top of the link when running forwards, are that there is a greater thrust and, therefore, more wear on the link trunnions and the bushings in the gear frame in which they work, than if the block was in the lower part of the link; and the slip of the link block, and hence the wear on the link, is greater. Besides, if the radius-rod hangers, hanger pins, or reverse-shaft arm should break when running at high speed, this radius rod would drop into backward gear, and if the reverse lever or reach rod should fail, both radius rods would fall into back gear. Under these conditions, the reversal of one or both valve gears would be certain to involve serious consequences.

40. **Difference in Thrust on Link-Trunnion Bearings.**—The purpose of Fig. 18 (*a*) and (*b*) is to show the difference in the thrust on the link fulcrum or trunnion bearings with the link block above and below the fulcrum point of the link in forward gear. It is assumed in (*a*) that the center of the link block is

9 inches below the center of the link fulcrum, and that it is 27 inches from the center of the link fulcrum to the center of the eccentric-rod pin hole. It is also assumed that it requires a force of 100 pounds to move the valve. The thrust exerted by the eccentric rod will be $\frac{100\times 9}{27}=33$ pounds, and the thrust on the link trunnion or fulcrum bearings will be $100-33=67$ pounds.

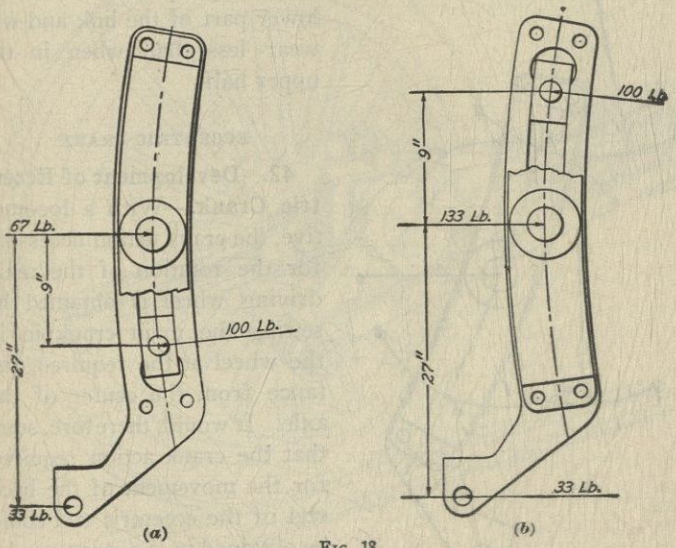


FIG. 18

In view (*b*) with the link block the same distance, or 9 inches, above the link fulcrum, the thrust exerted by the eccentric rod will be the same as before, or $\frac{100\times 9}{27}=33$ pounds. The thrust on the link-trunnion bearings, however, will be the sum of the forces on the ends of the link, or 133 pounds. Hence, the wear on the link trunnions and the trunnion bushings is doubled when the gear is designed to operate with the link block in the top of the link in forward gear. This requires the link to be reground oftener than otherwise would be necessary.

41. Link-Block Slip.—The reason why the link block slips less in the link, with the block in the lower half of the link than in the upper half, is shown in Fig. 19. The center *a* of the link block follows the arc *d*, and the bottom radius-rod hanger pin follows the arc *f*, when the link swings on the fulcrum point *c*. The link block when in the top of the link follows the arc *e*, and the radius-rod pin the arc *g*. As the arc *d* conforms more nearly to the arc *f* than the arc *e* to the arc *g*, it is evident that the link block will slip less when in the lower part of the link and will wear less than when in the upper half.

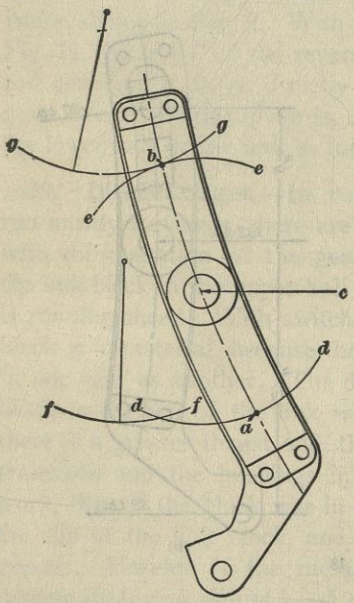


FIG. 19

ECCENTRIC CRANK

42. Development of Eccentric Crank.—With a locomotive, the crank action necessary for the rotation of the main driving wheel is obtained by setting the main crankpin in the wheel at the required distance from the center of the axle. It would, therefore, seem that the crank action required for the movement of the back end of the eccentric rod could be obtained in the same way by placing a pin in the driving wheel at the proper distance from the axle center. However, this cannot be done because two crankpins with a rod connecting to each cannot be placed on the same side of the wheel without one of the pins striking the other rod, and some other arrangement must be used.

For example, if the eccentric rod was connected to a crankpin shorter than the main crankpin, the main crankpin would strike the eccentric rod, when near the front dead center. The parts can be prevented from interfering by placing the eccentric crank *1* on the end of the main crankpin *c*, as in Fig. 20, and

this method of driving the eccentric rod is used with outside valve gears like the Walschaert and the Baker, each of which requires an eccentric crank on the outside of the driving wheel.

43. Action of Eccentric Crank.—The action of the eccentric crank can be more readily understood from Fig. 21, in which *a* is the center of the axle, *c*, the center of the main crankpin,

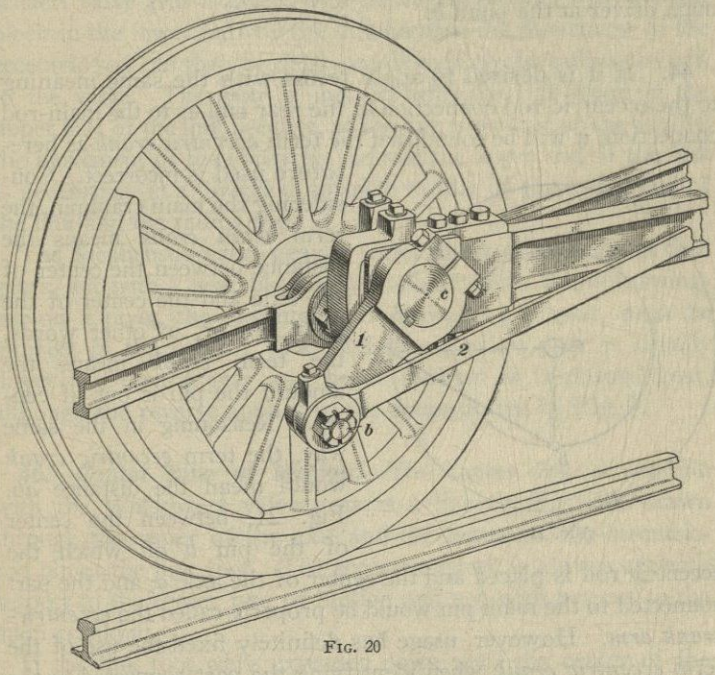


FIG. 20

and *b*, the center of the eccentric crankpin. The eccentric crank is shown by the line *bc*, the main crank by the line *ac*, and the distance between the center of the axle and the center of the eccentric crankpin by the line *ab*.

The eccentric crank *bc* is merely a straight arm with a crankpin *b* on the outer end. The arm is of such a length that when properly set, the center of the crankpin *b* stands far enough from the center of the axle *a* to give the required movement to the eccentric rod when the driving wheel turns. The length of the

crank formed by the eccentric crank *cb* is equal to *ab*, the distance between the center *a* of the axle and the center *b* of the eccentric crankpin. The throw of the eccentric crank or the maximum backward-and-forward movement imparted to the front end of the eccentric rod is equal to twice *ab*. If it were practicable to do so, the eccentric crank *bc* could be dispensed with, and the same effect obtained by inserting a crankpin in the main driver at the point *b*.

44. If it is desired to apply terms with the same meaning to the eccentric-rod connection at the rear end as to the main-rod connection, it will be found that the term *eccentric crank* as heretofore used is incorrect. Considering the main crankpin, the term *main crank* means the distance between the center of the axle and the center of the main pin or, in other words, the term *crank* means the amount the pin is out of center. Reasoning in the same way, the term *eccentric crank* would mean the distance *ab*, Fig. 21, between the center of the pin *b* on which the eccentric rod is placed and the center of the axle *a*, and the part connected to the main pin would be properly called the *eccentric-crank arm*. However, usage has definitely fixed the use of the term *eccentric crank* when identifying the part connected to the main crankpin, and to prevent confusion, the same practice will be followed in this Section.

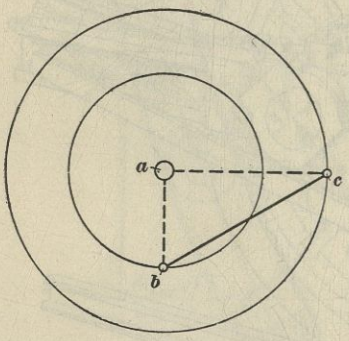


FIG. 21

It will be found more convenient to consider a line between the center of the axle and the center of the eccentric crankpin as the eccentric crank if the relative position of the main crank and eccentric crank is measured by an angle. The action of the eccentric crank in imparting movement to the eccentric rod and its position with respect to the main pin can also be more readily understood if the above dimension is considered.

POSITION OF ECCENTRIC CRANK

45. Direct and Indirect Motion.—The motion of a valve gear or the gear is said to be *direct* when the eccentric rod moves in the same general direction as the valve. The motion is indirect when these parts move in opposite directions. The Walschaert valve gear is direct with the engine moving with the link block in the lower half of the link because the movement of the eccentric rod can then be delivered directly to the radius rod and to the valve. The gear is indirect with the link block in the upper half of the link because, as the link is pivoted at the middle, the movement of the eccentric rod and the lower end of the link is necessarily in a direction opposite to that of the upper end of the link and the radius rod.

The Stephenson valve gear is either direct or indirect in both gears, but with a gear like the Walschaert with the link swinging on a pivot, the movement, if direct in one gear, must be indirect in the other. The Walschaert valve gear is usually direct in forward gear and hence indirect in backward gear, although the reverse applies to the arrangement in Fig. 9.

46. Center Line of Motion.—The center line of motion with the Walschaert valve gear is a line *ce*, Fig. 13, drawn through the center of the axle and the center of the eccentric-rod pin at the link foot. The eccentric crank is always set with respect to the center line of motion and not with respect to the main crankpin.

If the link foot were extended down until the center of the eccentric-rod pin was on the line drawn through the center of the main axle and the center of the cylinder, or the center line of the engine, the center line of motion, and the center line of the engine would coincide. In this event the eccentric crank would occupy the same position with respect to the main crankpin as it would to the center line of motion.

However, it would be impracticable to lengthen the link foot to such an extent, as it would require an eccentric crank of excessive throw for the link to swing far enough to give the required movement to the link block and the radius rod. With the link

foot above the center line of the engine, the center of the eccentric crankpin d with the arrangement in Fig. 13 is slightly behind the top quarter position d', when the main crankpin is on the front dead center.

The center of the eccentric crankpin comes very near the quarter positions with the main crankpin on the dead center, and hence is about one-quarter of a turn from the main pin. Therefore, the position of the eccentric crank will be identified by stating its location with respect to the main pin rather than to the center line of motion.

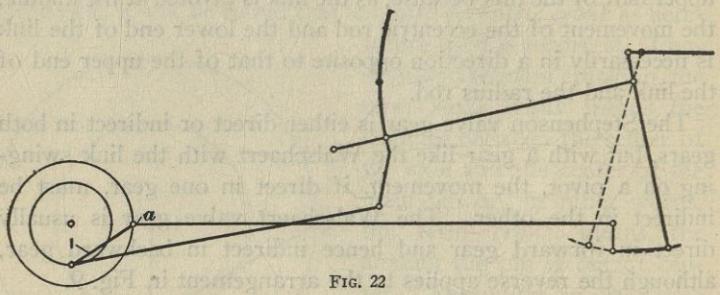


FIG. 22

47. Conditions on Which Position Depends.—The position of the eccentric crank depends on whether the valve is an outside- or inside-admission valve, and whether the motion is direct or indirect.

48. Outside-Admission Valve and Direct Motion.—With an outside-admission valve and direct motion in forward gear, Fig. 22, the eccentric crank *1* is about one-quarter of a turn ahead of the main crankpin *a* when the locomotive is running forwards, and the same distance behind it when the locomotive is running backwards. With the main pin on the front dead center and the engine moving forwards, the eccentric crank will move the valve back or to the left, and this is the valve movement desired. In Fig. 14 is shown the eccentric crank in the same position as in Fig. 22.

49. Inside-Admission Valve and Indirect Motion.—With an inside-admission valve and indirect motion in forward gear,

Fig. 23, the eccentric crank is set in exactly the same position as in Fig. 22.

50. Outside-Admission Valve and Indirect Motion.—With an outside-admission valve and indirect motion in forward gear,

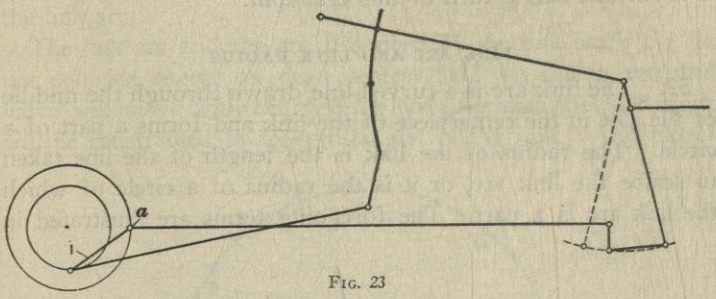


FIG. 23

Fig. 24, the eccentric crank *1* is about one-quarter of a turn behind the main crankpin *a* when the locomotive is running forwards and the same amount ahead of the pin when running backwards. The eccentric crank when so set moves the eccentric rod ahead when the main pin turns forward from the front dead

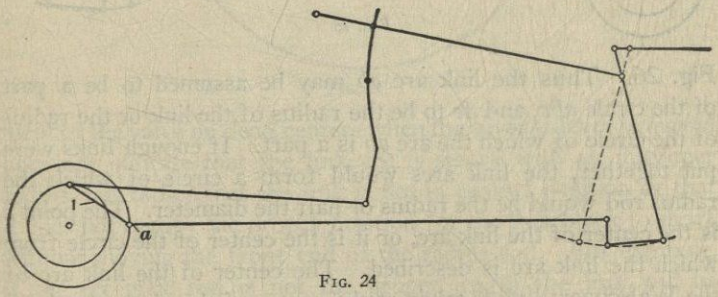


FIG. 24

center, and this causes the top of the link and the radius rod to move to the left and pull the valve back or in the direction required.

51. Inside-Admission Valve and Direct Motion.—With an inside-admission valve and direct motion, Fig. 25, the eccentric crank is set in exactly the same position as with an outside-

admission valve and indirect motion, Fig. 24. In Fig. 11 is shown a gear arranged for direct motion and inside admission. It will be noted that the center of the eccentric crankpin is either about one-quarter turn behind the main pin or about the same amount ahead of it, and that the difference between the positions is about one-half a turn of this crankpin.

LINK ARC AND LINK RADIUS

52. The link arc is a curved line drawn through the middle of the slot in the centerpiece of the link and forms a part of a circle. The radius of the link is the length of the line taken to scribe the link arc, or it is the radius of a circle of which the link arc is a part. The foregoing terms are illustrated in

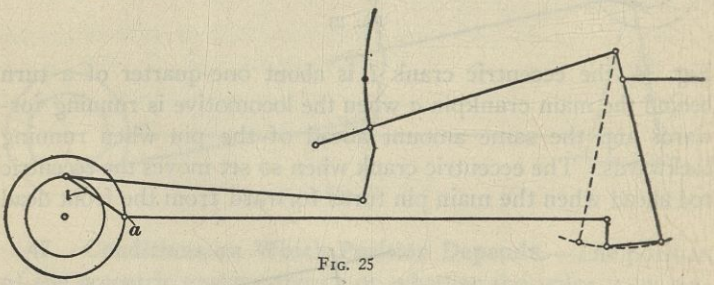


FIG. 25

Fig. 26. Thus the link arc *ab* may be assumed to be a part of the circle *abc*, and *de* to be the radius of the link or the radius of the circle of which the arc *ab* is a part. If enough links were put together, the link arcs would form a circle of which the radius rod would be the radius or half the diameter. The point *e* is the center of the link arc, or it is the center of the circle from which the link arc is described. The center of the link arc of the Walschaert link is taken at the center of the pin in the front end of the radius rod, and the link radius or the length of the line taken to describe the link arc is the distance between the center of the radius-rod pin and the center of the link-block pin.

53. Constant Lead.—The link is said to be in central position when the center of the link arc falls on the center of the radius-rod connection to the combination lever, and the link

occupies this position when the engine is on either dead center. Therefore, the reason that the lead remains unchanged or constant is that the link is in central position on the dead centers, and the center of the link-block pin when the radius rod is raised and lowered conforms with or follows exactly the curvature of the link arc.

The link arc and the arc described by the link-block pin do not coincide except on dead centers and the radius rod and valve will move with the reverse lever because the link block will be constrained to follow the slot in the link. Any move-

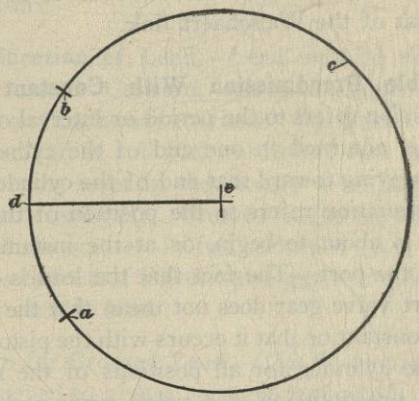


FIG. 26

ment of the valve on dead centers when the reverse lever is moved does not indicate that the link arc is struck with an improper radius, but rather that the link is not in central position or that it does not occupy the proper position for the link block to move without moving the front end of the radius rod. For example, if the eccentric rod is not the proper length the link will be slightly inclined on the dead centers, and the front end of the rod and, therefore, the valve will move when the reverse lever is shifted.

54. Curvature of Link With Walschaert and Stephenson Gears.—The curvature of the link with the Walschaert valve gear is in the direction opposite to that of the link of the Stephenson valve gear, owing to the position of the point from which

the link arc is struck, or to the location of the center of the link arc.

With the Walschaert valve gear, the center of the link arc is in front of the link or at the center of the radius-rod pin, hence the link arc curves toward its center or forwards as in Fig. 26, where the arc *ab* curves toward the center *e*.

With the Stephenson valve gear, the center of the link arc is taken at the center of the eccentric and is behind the link, and the link radius is equal to the distance between the center of the eccentric and the center of the link. The link arc curves toward the link-arc center, therefore the link curves in the direction opposite to that of the Walschaert link.

55. Variable Preadmission With Constant Lead.—The term *preadmission* refers to the period or interval of time during which steam is admitted to one end of the cylinder while the piston is still moving toward that end of the cylinder. The term *point of preadmission* refers to the position of the valve when preadmission is about to begin, or at the instant the valve is about to open the port. The fact that the lead is constant with the Walschaert valve gear does not mean that the point of preadmission is constant or that it occurs with the piston in the same position in the cylinder for all positions of the reverse lever. The point of preadmission is a valve event and is influenced by the movement of the reverse lever in the same way as other valve events, such as cut-off and release, etc. The valve events all occur earlier in the stroke of the piston when the lever is drawn up, and later in the stroke as the lever is dropped down. Therefore while the lead is always the same with the piston at the end of the stroke, yet the position of the piston when the steam begins to enter the cylinder varies, or the point of preadmission varies, according to the position of the reverse lever.

CROSSED LEAD

56. Purpose of Lead.—The chief purpose of lead is to increase the port opening at running cut-offs. At maximum cut-off the port opening is ample and lead is then of no particular advantage; rather it is a handicap, because it hastens the cut-off

and thus impairs the ability of the locomotive to start heavy trains. Passenger locomotives require good lifting power so as to start trains smoothly; also, as these locomotives are run at comparatively short cut-offs, the port opening should be ample to maintain speed. For these reasons it is sometimes the practice to design the Walschaert valve gear with crossed lead. In such a case the minimum lead is obtained in full gear, thus insuring a longer maximum cut-off and hence more starting power; a greater lead is secured at short cut-offs, thereby giving ample port opening. Crossed lead also delays the point of closure, thereby reducing the compression and hence increasing the mean effective pressure.

57. Classification of Lead.—Lead may be either constant, variable, or crossed. Constant lead is the same in all cut-offs, both forward and backward motions. Variable lead is the least in full forward and in full backward gears and increases to the maximum with the lever in the center. The Stephenson valve gear is a variable lead gear. Crossed lead is the least in full forward gear and the greatest in full backward gear. Crossed lead with the Walschaert and Baker valve gears is sometimes incorrectly termed variable lead.

58. Design for Crossed Lead.—The Walschaert valve gear is usually designed to give a constant lead; such a design gives a constant lead at all cut-offs in both motions. Crossed lead can only be obtained by varying from the ordinary design, or it is obtained by offsetting the eccentric crank from its right-angle position the amount necessary to change the lead. However, it must not be assumed that the valve travel will be the same as before, even though the crank circle is the same; the travel will be greater in one gear than in the other. The average of the valve travels in both gears will be very close to the specified valve travel.

59. In Fig. 27 the top line indicates the original position of the eccentric crank for direct motion in forward gear, and inside admission valves; the other lines indicate the position of the crank when making the change to crossed lead. Moving the

center of the eccentric crank from *a* to *b* would decrease the lead in forward gear to the required amount, but the inner eccentric crank circle then scribed by the crank would not give the proper crank circle, as the crank would be too short. To preserve the original circle, the center of the crank must follow the large

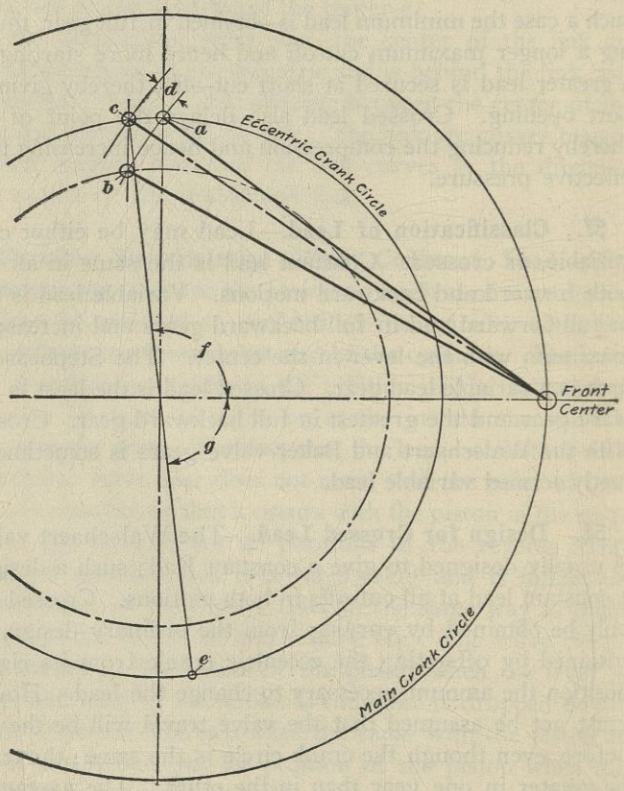


FIG. 27

eccentric-crank circle. This requires the center of the crank to be located at *c*, which in turn necessitates a crank of a greater length than the original one by an amount equal to *d*.

With an outside admission valve and direct motion in forward gear, the eccentric crank will have to be shortened because a decrease in the lead requires the crank to be moved away from

the center of the axle as in Fig. 28. The eccentric crank, after its center has been moved from its original position at c to the point b, must be shortened an amount equal to d and the center located at the point c in order to bring it on its original circle.

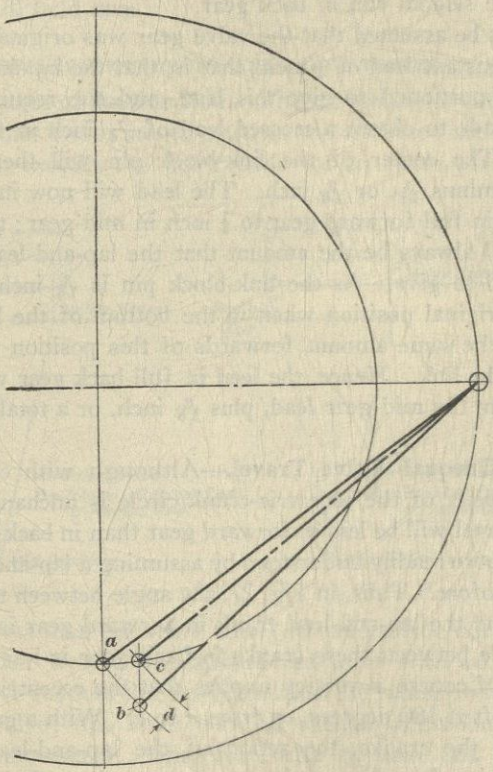


FIG. 28

The gear is never set for crossed lead until the correct length of the eccentric crank has been determined in the drafting office. Then, when setting the valves, all that is necessary is to locate the crank the proper distance from the center of the axle to give the specified lead in full gear or the correct eccentric-crank circle. A gauge especially adapted for this purpose is generally provided in railroad shops.

60. Increase in Lead.—If, as with crossed lead, the eccentric crank is moved to decrease the lead in full forward gear, the lead will continue to increase until the lever is in full back gear, where it reaches its maximum. The heavy lead in full back gear is comparatively unimportant with passenger locomotives because they are seldom run in back gear.

Let it be assumed that the valve gear was originally designed for a constant lead of $\frac{1}{4}$ inch; that is, that the lap-and-lead lever was proportioned to give this lead, and the required changes were made to obtain a crossed lead of $\frac{1}{16}$ inch in full forward gear. The center of the link-block pin will then be drawn back $\frac{1}{4}$ minus $\frac{1}{16}$, or $\frac{3}{16}$ inch. The lead will now increase from $\frac{1}{16}$ inch in full forward gear to $\frac{1}{4}$ inch in mid-gear; the mid-gear lead will always be the amount that the lap-and-lead lever was designed to give. As the link-block pin is $\frac{3}{16}$ inch to the rear of its original position when in the bottom of the link, the pin will be the same amount forwards of this position when in the top of the link. Hence, the lead in full back gear will be equal to $\frac{1}{4}$ inch, the mid-gear lead, plus $\frac{3}{16}$ inch, or a total of $\frac{7}{16}$ inch.

61. Unequal Valve Travel.—Although with crossed lead the diameter of the eccentric-crank circle is unchanged, yet the valve travel will be less in forward gear than in back gear. This can be more readily understood by assuming a lap-and-lead crank as heretofore. Thus, in Fig. 27, the angle between the eccentric crank and the lap-and-lead crank in forward gear is equal to f; the angle between these cranks in back gear is less or is equal to g. Of course, reversing implies that the eccentric crank has been shifted 180 degrees, or from c to e. With a greater angle between the cranks, the action of the lap-and-lead crank in neutralizing the action of the eccentric crank on the valve occurs earlier in its travel than when the angle is less; this results in a lesser valve travel and a smaller steam-port opening in forward gear. The smaller angle between the cranks in back gear causes the lap-and-lead crank to begin to neutralize the action of the eccentric crank later, and hence the valve travel is increased. Therefore, the shorter travel in forward gear and a greater travel in back gear is due to the angle between the cranks being

greater in the former case than in the latter. As already explained, the action of the lap-and-lead crank is equivalent to that of the combination lever. The foregoing applies to inside admission and direct motion and outside admission and indirect motion as in Fig. 27. With the conditions shown in Fig. 28, the reverse will hold true.

RADIUS-ROD MOVEMENT AND VALVE TRAVEL

62. Movement of Radius Rod.—The movement of the front end of the radius rod is never equal to the travel of the valve; this movement exceeds the valve travel for an inside admission

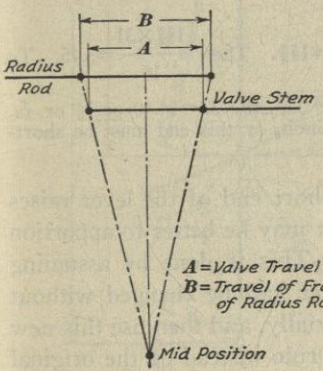


FIG. 29

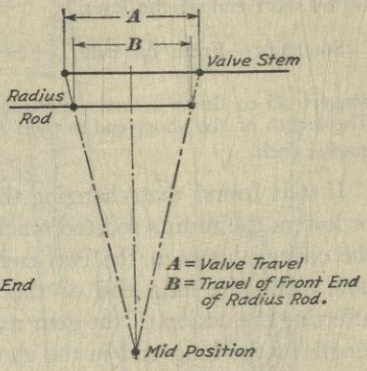


FIG. 30

valve and is less than the valve travel for an outside admission valve. In other words, the lap-and-lead lever with an inside admission valve reduces the movement that the radius rod transmits to the valve; this lever with an outside admission valve increases the movement. Therefore, with the same link swing, the valve travel is longer with an outside admission valve than with an inside admission valve. The foregoing is illustrated in Figs. 29 and 30. The valve movement as well as the movement of the front end of the radius rod when the reverse lever is shifted from one corner of the quadrant to the other with the crosshead in central position, is as shown. The movement of the radius rod exceeds the movement of the valve for inside admission and is less than the valve movement for outside admission.

63. Changing the Lead.—To increase the lead it is necessary to make the short end of the combination lever longer; to decrease the lead, this end must be made shorter.

The following rule gives the length of the short end of the lever for either a decrease or an increase in lead.

Rule.—*First add $\frac{1}{32}$ inch to the lap and to the lead desired to allow for lost motion; next multiply this lap and lead by the long end of the lever for outside admission and by the complete lever for inside admission, then divide by one-half the stroke.*

EXAMPLE.—Let it be assumed that it is required to decrease the lead of the valve gear shown in Fig. 31 from $\frac{3}{8}$ to $\frac{1}{4}$ inch. Find the length of the short end of the lever.

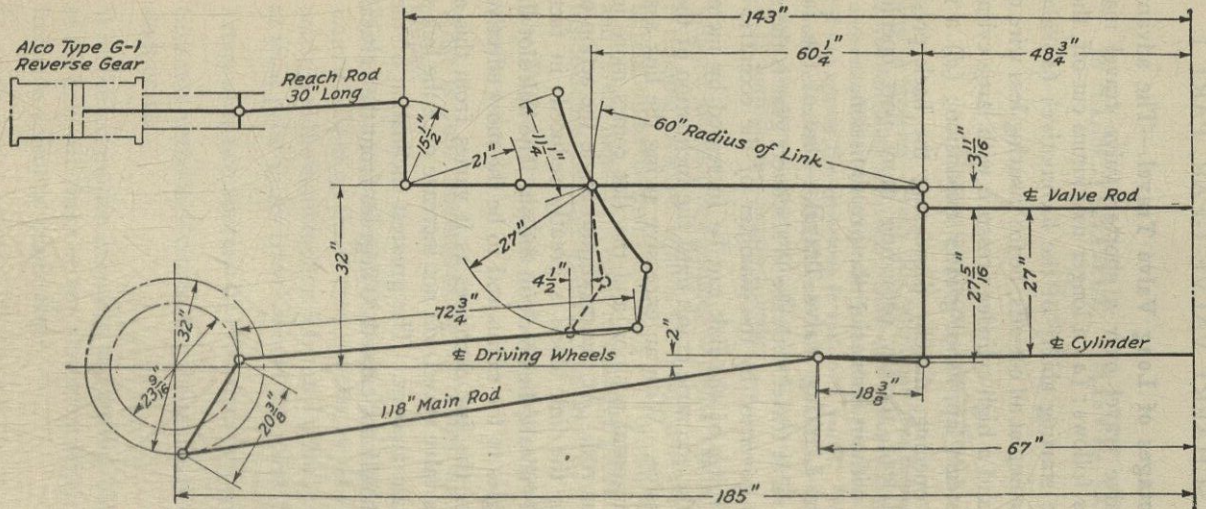
SOLUTION.—From the rule $1\frac{1}{2}+\frac{1}{4}+\frac{1}{32}=1\frac{25}{32}$. Then $\frac{1\frac{25}{32}\times 31}{16}=3.45$. To convert .45 to thirty-seconds, multiply by 32, $.45\times 32=14.40$ or $\frac{14}{32}$ or $\frac{7}{16}$. The length of the short end is then $3\frac{7}{16}$ inch, or this end must be shortened $\frac{1}{4}$ inch.

If it is found that changing the short end of the lever raises or lowers the radius rod too much, it may be better to apportion the change between the two ends. This is done by assuming how much the long end of the lever can be changed without affecting the action of the gear materially, and then use this new length of the long end in the above rule instead of the original length. It should be noted, when following the last plan, that the long end is to be shortened when calculating an increase in lead and lengthened when calculating a decrease.

Any alteration requires a new combination lever, and a change of this nature must, of course, be sanctioned by the proper authority.

DIMENSIONS OF WALSCHAERT VALVE GEAR

64. Copy of Print.—A copy of a print that shows the dimensions of all of the parts of the Walschaert valve gear designed to give a long valve travel is shown in Fig. 31. The size of the cylinders, the valve travel, the steam lap, and the lead are also indicated. The distance between the center of the main driving axle and the vertical center of the cylinders is 185 inches.



Cylinders 28"X 32"
Piston Valve 9" Travel.
Inside Admission.
Direct Motion.

VALVE
Lead - Constant - 3/8"
Steam Lap - 1 1/2"
Exhaust Clearance - Line and Line.

FIG. 31

65. Advantages of Long Valve Travel.—The advantages of a long valve travel over a shorter valve travel may be enumerated as follows: (*a*) a longer maximum cut-off, thereby increasing the starting ability of the locomotive; (*b*) a wider steam-port opening at all cut-offs, hence insuring less wire drawing of steam and a high cylinder pressure with large cylinders; (*c*) a wider steam lap, hence greater expansion; (*d*) a wider exhaust port opening, thereby decreasing the back pressure; (*e*) increased lead, thereby providing more port opening at short cut-offs without increasing the preadmission.

66. Factors Limiting Valve Travel.—One of the factors that limit the valve travel with the Walschaert gear is the swing of the link as governed by the diameter of the eccentric-crank circle. The swing of the link can be increased by increasing the throw of the eccentric crank until the inclination of the link becomes excessive. With an excessive swing the link assumes more of a horizontal position and the slot comes more in line with the radius rod. At the maximum angle the action of the link in moving the link block is greatly reduced; in fact, the link will merely rotate the block on the pin. The link slot should be at right angles to the radius rod to be the most effective, the effectiveness of the link decreases as it varies from this angle. Therefore, the valve travel will not increase once the link swing reaches a certain amount. The greatest inclination of the link or its swing should not exceed 30 degrees from the vertical.

WALSCHAERT VALVE GEAR

Serial 4003A–3 PART 1 Edition 2

Examination Questions

Notice to Students.—Study this instruction text thoroughly before you answer the following questions. Read each question carefully and be sure you understand it; then write the best answer you can. You will profit most if you answer the questions in your own words. When you complete your work, examine it closely, correct all the errors you can find, and see that every question is answered; then mail your work to us. DO NOT HOLD IT until another lesson is ready.

1. When a locomotive equipped with the Walschaert valve gear is running forward, what is the position of the eccentric crank in relation to the main crankpin with outside-admission valve and direct motion? With locomotive running forward and inside-admission and indirect motion?
2. The Walschaert valve gear has many special advantages; what are they?
3. What is your understanding of a link arc and of a link radius?
4. With the crosshead at the exact dead center of its travel, main crankpin on the bottom quarter, reverse lever in center notch, and the combination lever in a plumb vertical position, at what point in its travel should the valve be standing?
5. From what two sources do the valves receive their motion?
6. Give two methods of connecting the radius rod to the reverse-shaft crank.
7. With the locomotive in motion and the link block in the center of the link, will there be any movement imparted to the valve from the eccentric crank arm?
8. Under the same conditions as in Question 7, could movement be imparted to the valve from any other source?

9. Movements of certain parts of the valve gear will indicate whether the motion imparted is direct or indirect, what are these parts?

10. Generally, what type of lead is applied to a Walschaert gear?

11. The combination lever performs two outstanding functions; what are they?

12. Where are the principal variations in the arrangements of the valve gear found?

13. What are the disadvantages of arranging the gear to work with the link block in the upper half of the link in forward gear?

14. With an inside admission valve, at what point is the radius rod connected to the combination lever? With an outside admission valve?

15. In what simple way can an inside or outside admission valve be ascertained?

16. In a brief manner, outline the three different types of valve lead as applied to steam locomotives.

17. Would you consider lead on a locomotive valve, an advantage or a handicap?

18. With the reference to the valve events, what change is brought about when the reverse lever is moved from a corner notch on the quadrant toward the center notch?

19. What parts of the valve gear are directly involved in transmitting movement to the valves when the locomotive is in motion?

20. Which parts of the valve gear are put in motion by the use of the reverse lever?

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